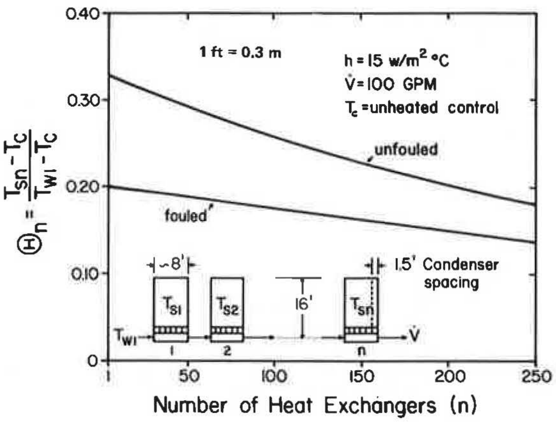
Figure 8. Variation of θ_n with number of unfouled and fouled SETA 18-in heat-pipe modules in series.



freezing and to significantly reduce the duration of snow cover on road (4,7) and bridge (5) surfaces by transferring thermal energy from the ground itself. The undisturbed winter ground temperatures 3 m (10 ft) or more below the surface were only of the order of 6°-10°C at these sites. The performance of a Glenwood-type heating system at these sites with the water temperature matching the local undisturbed ground temperature would have been superior to these ground heat-pipe systems due to the cooling of the earth around the ground heat pipes. Wells, municipal water lines, and waste water such as sewerage may therefore prove to be feasible energy sources for roadway heating systems.

In summary, all Glenwood heat-pipe modules were very effective as snow-melting systems, even when they were severely fouled. This was accomplished essentially with 25°C water at flow rates around 35 gal/min. Even at this low flow rate, the system could have supported a fairly large number of these modules in series without a large degradation in the performance of the last units. In situations requiring just the elimination of preferential icing or only requiring a limited snow-melting capability, this heating system could effectively use water with temperatures as low as 10°C.

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Publication of this paper sponsored by Committee on Winter Maintenance.

Construction and Benefits of Rubber-Modified Asphalt Pavements

DAVID C. ESCH

A paving system was developed in Sweden in the 1960s in which relatively large rubber particles were incorporated into asphalt-concrete pavements. The original purpose was to increase skid resistance and durability. This system, distributed under the trade names Skega Asphalt or Rubit in Scandinavia and PlusRide in the United States, was also found to provide a new form of winter ice control because of the increased flexibility and the action of protruding rubber particles. The Alaska Department of Transportation and Public Facilities installed five experimental pavement sections by using the PlusRide system between 1979 and 1981. Major modifications to normal asphalt pavement aggregate gradations, asphalt contents, and mix design procedures are considered essential to achieve durable nonravelling rubber-asphalt pavements. Laboratory tests of PlusRide paving mixes also indicate a potential for greatly increased pavement fatigue life as a result of the elasticity of this material. The attainment of low voids in the pavement is the primary design and construction objective, and mix design and construction activities are discussed. Observations of the skid-reduction benefits under icy road conditions have been made with a British pendulum tester and a vehicle equipped with a Tapley brake meter. Tests indicate that significant reductions in icy-road stopping distances nearly always resulted from the use of the PlusRide paving system. For 19 testing dates over two winters, stopping distances were reduced by an average of 25 percent; reductions on specific dates ranged from 3 to 50 percent.

In the late 1960s, experimentation was done in Sweden on the effects of mixing rubber particles in asphaltic pavements. A system incorporating 3-4 percent by weight of relatively large (1/16 in to 1/4 in) rubber particles into an asphalt pavement was developed to increase skid resistance and durability and was found to provide a new form of winter ice control as well as a reduced noise level. The ice-control mechanism apparently results from the flexing of the protruding rubber particles and the

greater flexibility of the mix under traffic action, which cause a breakdown of surface ice deposits.

Roadway surface-ice deposits become a major problem in urbanized areas with high traffic volumes and stop-and-go traffic movements. Costs of maintaining ice-free pavements by using deicing chemicals or improving traction by using sand applications are very high and would justify considerably increased expenditures on pavement construction if ice-free pavements could be obtained.

An unrelated problem, but one of considerable magnitude, has been the disposal of the hundreds of millions of used tires discarded each year. The possibility of using this form of refuse to the benefit of the public must be seriously considered.

Encouraged by the successes of rubber-asphalt paving mixes in Scandinavia, the Alaska Department of Transportation and Public Facilities installed five experimental pavement sections in Fairbanks and Anchorage between 1979 and 1981 by using different pavement mixtures. Periodic measurements of surface friction have been made during icy winter conditions in 1980 and 1981 to analyze the benefits of the rubber in increasing traction and reducing stopping distances. Laboratory tests for resilient modulus and durability have also been performed on samples of these mixes; they indicate that major increases in fatigue life and crack-reflection control are anticipated due to the increased flexibility.

BACKGROUND

Asphalt and Rubber Mixtures

The original development work in the area of coarse rubber-asphalt paving mixtures was performed by the Swedish companies Skega AB and AB Vaegfoerbaettringar (ABV). The material application was patented under the trade name Rubit. In America, the trademark PlusRide asphalt is now used to designate this material.

It should be noted that considerable experimental work and field trials have been performed in the United States, particularly in Arizona, California, and Colorado, on rubberized asphalt seal coats (1,2). These installations have used finely ground (-No. 16 to +No. 25) crumb rubber reacted with asphalt at elevated temperatures to form a thick elastomeric material, which is then diluted with 5 percent kerosene to aid in application. It was learned from studies by the Arizona Department of Transportation that these small rubber particles swell to two to three times their original size when reacted with asphalt at temperatures of 350-400°F for periods of 30 min or more (3). As such, these installations differ substantially from the materials discussed here. Little or no use of the concept of incorporating larger rubber particles in pavement surfacing layers is indicated in North America. The potential savings in ice-control costs may justify the increased cost of rubberized surfacings. Use of such surfacings on bridge decks and on insulated roadway sections should offset the icing occurrences commonly noted on bridges and sometimes found over insulated sections of roadway.

Ice-Control Considerations

The use of sands for ice control provides only temporary skid resistance, and sand must be reapplied often. Stopping distances on sanded ice are also much greater than on dry pavement. In addition, sand must be removed from gutters and inlets in urban areas following spring thawing to avoid blockage of drainage systems.

Some recent analyses of the costs and benefits of using salt to remove roadway ice have indicated that the ultimate costs to the road user may be more than 10 times as high as the sum of the benefits (4, p. 969). The major cost item, premature vehicle destruction through corrosion, greatly outweighed the benefits of reduced maintenance and accident costs. Salts also present the possibility of contamination of ground and surface waters from roadway runoff. Benefits of salt use that are difficult to quantify, however, are the savings in travel time and reduced accident levels that result when roadways are free of ice.

PAVING MIX CONSIDERATION

Aggregate and Rubber Proportions

From experience in Sweden, three different aggregate (sand and gravel) gradations are currently recommended to serve different traffic levels, as shown by Table 1.

The rubber particles used in these mixes are produced in roughly cubical form from grinding waste tires, which have first had the steel wires in the tire-bead area removed. The rubber may include some tire cord and steel fibers from the tire belts and is required to meet the gradation specifications in Table 2. Product experience by the parent company, ABV, has indicated that some durability benefits result from the use of a modified rubber gradation, replacing 20 percent of the originally used coarse rubber with a finely ground (No. 10-40) rubber size. This change corresponds with use of a similar rubber grading in the construction of the rubberized asphalt seal coats previously mentioned and was the basis of Alaska's modified rubber gradings used in 1981.

To those knowledgeable in the area of design of asphalt paving mixtures, a review of these specifications will reveal some critical differences between modified and normal pavements. The most important difference is indicated by the shape of the aggregate gradation curve (Figure 1). To provide space for the rubber particles, it is necessary to create a gap in the gradation curve for the aggregates, primarily in the 1/8-in to 1/4-in size range. In effect, the rubber particles replace the rock particles that normally occupy this size range. Unless this gradation-curve gap is present, the rubber particles will resist compaction of the mix during the rolling operation, and the resultant pavement will have excessively high voids and no durability.

Asphalt Content Determination

The asphalt content recommended in Table 1 will generally be found to be 1-2 percent higher than that in conventional mixes. This higher asphalt level is an important factor in the durability of rubber-asphalt pavements. Laboratory mixes should be prepared at several different asphalt contents. Compaction and testing are performed by using the Marshall procedure, in which samples are placed in greased open-ended steel ring molds and compacted with 50 blows of a drop hammer on each end. Samples are then weighed both in air and immersed in water, and the percentage of voids is determined by calculation. As the asphalt content is increased, the voids will decrease as shown in Figure 2. It has been found critical to achieve low voids and thereby prevent the intrusion of water. The minimum asphalt content permitted should be that at which 3 percent voids is achieved. Marshall stability criteria cannot normally be met with PlusRide paving mixes. Stabilities as low as 350 lb were recorded for the

paving mixes used in the 1979 Fairbanks installations, yet these pavements have resisted bleeding in the two years since construction, in spite of air temperatures as high as 90°F.

Table 1. Recommended specifications for rubber-asphalt (PlusRide) paving mixtures for different levels of traffic.

	Mix		
Characteristic	PlusRide 8	PlusRide 12	PlusRide 16
Average daily traffic	2500	2500-10 000	10 000
Minimum thickness (in)	0.75	1.5	1.75
Aggregate (% passing) sieve size			
3/4 in	-	-	100
5/8 in	-	100	-
1/2 in	-	-	65-80
3/8 in	100	60-80	50-60
1/4 in	60-80	30-42	30-42
No. 10	23-38	19-32	19-32
No. 30	15-27	13-25	12-23
No. 200	7-11	8-12	6-10
Preliminary mix design			
Rubber (% of total mix)			
By weight	3.0	3.0	3.0
By volume (approx.)	6.7	6.7	6.7
Asphalt (% of total mix)			
By weight	7.5	7.5	7.5
By volume (approx.)	20.2	20.2	20.2
Maximum voids (%)	2	3	4

Table 2. Particle size specifications for rubber.

	Percent Passing			
Sieve Size	Alaska 1979-1980	Alaska 1981	ABV Combined Coarse and Fine	PlusRide 1981
1/4 in	-	-	100	-
No. 4	100	100	76-92	100
No. 10	15-35	15-36	28-36	28-40
No. 20	-	10-25	10-24	-
No. 40	0-6	-	-	0-6
No. 200	0-2	-	-	-

The differences in mix properties that can occur within the aggregate size specification limits used for the Fairbanks rubber-modified pavements in 1981 were studied by performing four mix designs by using a single aggregate source, AC-2.5 asphalt, and a rubber content of 3 percent. Gradings used in this study are shown in Figure 3 and represent the coarse and fine gradation limits (Mixes A and B), the middle of the specification band (Mix C), and the straightest-line grading possible with this specification band (Mix D). Results of this testing at asphalt contents from 6 percent to 9 percent by weight of the dry aggregate are shown in Figures 4-6 and demonstrate the low stability and high flow-test results typically obtained on these mixes as well as the sensitivity of the void levels and other mix properties to aggregate gradation changes. It should be noted that these specification limits (Figure 3) are wider than those recommended for the similar PlusRide 12 mix in Table 1, and this specification band was used by the Alaska Department of Transportation to provide more contractor flexibility in choice of a final mix gradation. It is obvious from this study that a good laboratory mix design is critical to obtaining a proper mix with low voids and adequate stability. The minimum required value for stability of these mixes has not yet been determined.

FATIGUE-LIFE ASPECTS

A series of laboratory fatigue tests have been performed on PlusRide paving mixes at Oregon State University to analyze the resistance of these mixes to failure in tension under the diametral split-tension test mode. In this work, samples were loaded to failure at selected tensile strain levels. Results as shown in Figure 7 indicate that the fatigue life of PlusRide pavements may be more than 10 times greater than that of normal mixes. This testing program provides hope that the PlusRide paving system might prove of benefit in roadways over weak foundations where fatigue cracking is the dominant failure mode.

Figure 1. Comparative aggregate gradation curves for normal and PlusRide asphalt-rubber pavements.

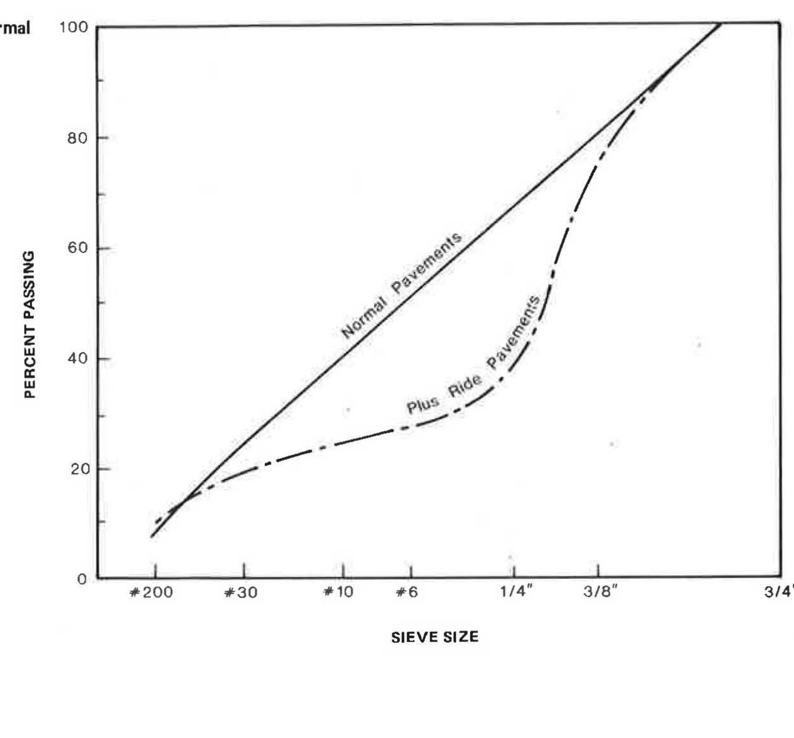


Figure 2. Asphalt content determination on basis of voids in mix.

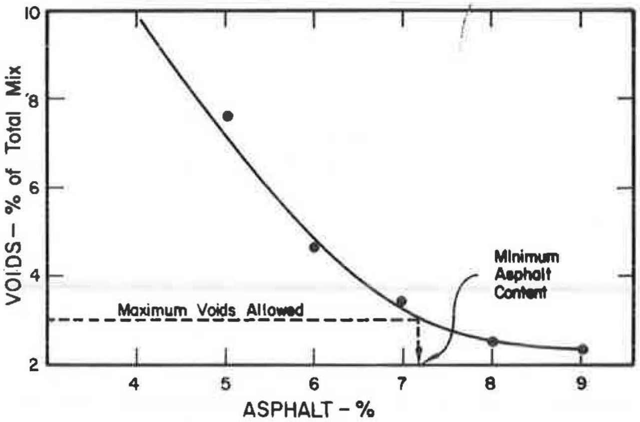


Figure 3. Aggregate gradations used to test for variations in mix properties due to gradation variations within specification band.

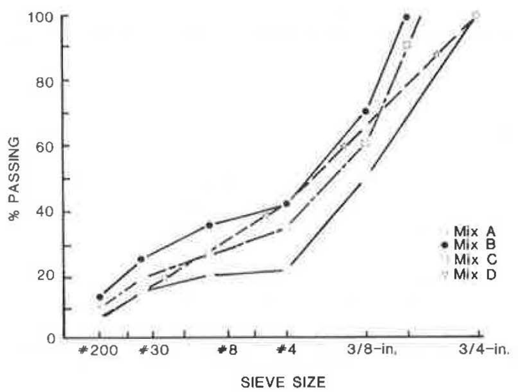


Figure 4. Differences in void content for different aggregate gradations within single specification band.

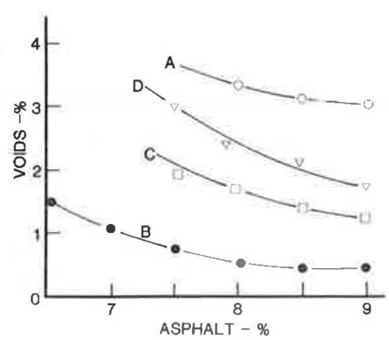


Figure 5. Differences in Marshall stability for different aggregate gradations within single specification band.

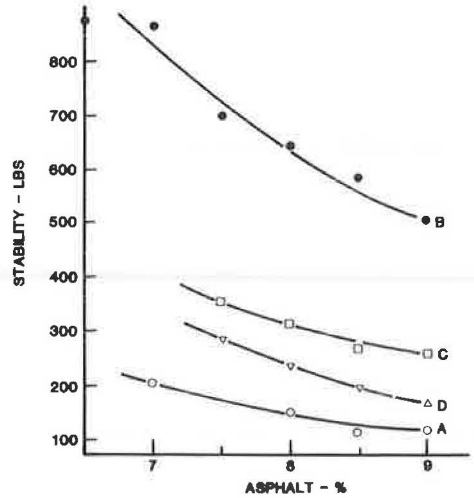
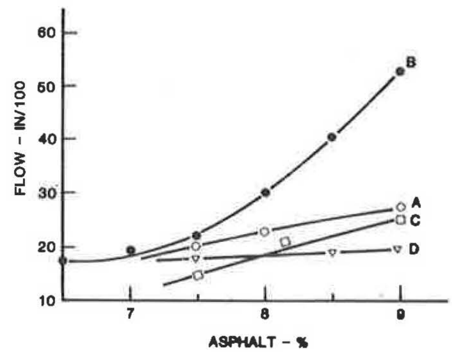


Figure 6. Differences in Marshall flow for different aggregate gradations within single specification band.



SPECIAL CONSTRUCTION CONSIDERATIONS

Mixing

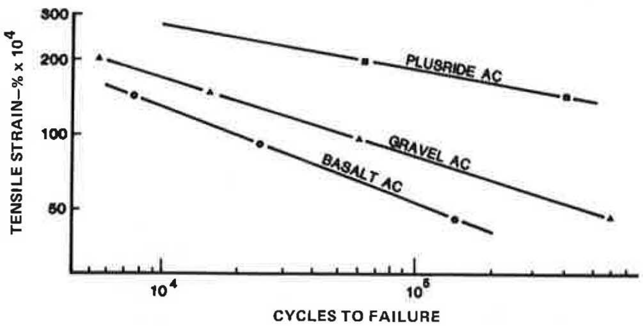
In the preparation of rubber-asphalt paving mixes, use of a batch mixing plant is preferred because the required quantities of rubber, asphalt, and aggregates can be measured exactly and added separately to the pug mill or mixing chamber. In this type of plant, preweighed sack rubber can be used to advantage, with quantity control by bag count. However, both continuous-mix and drum-dryer mix asphalt paving plants have been used without difficulty. In these plants, in which the mixing operation goes on continuously rather than in batches, the rubber must be added continuously from a separate bin with a belt feed to maintain uniformity. Very close control of the rubber content is critical to assure proper field performance. Mixing temperatures and asphalt grades used are similar to those for normal paving mixes, with some indications that mixes may benefit from blending at temperatures as high as +350°F.

Placement and Compaction

Placement of the hot paving mix should be performed by paving machines equipped with full-width vibratory screeds. Rolling should commence as soon as possible after placement without the mix sticking to the roller and should continue until the mix temperature cools below 140°F. Rubber mixes are very resilient and rebound noticeably behind the roller. Rollers may be either steel-wheel static or vibratory types. Rubber-tire rollers were not to be used, according to original recommendations. However, recent experiences with rubber-asphalt pavements placed in Vancouver, B.C., and Anchorage, Alaska, in 1981 indicate that significant surface tightening might be achieved by use of a rubber-tire roller after the mix has cooled below 140°F.

Compaction to the highest possible density with minimal voids is essential to good pavement performance. When core samples are taken from the finished pavement and tested, the average void content should be less than 5 percent. Rubber-asphalt paving mixes will appear excessively high in asphalt content to personnel familiar with normal mixes, but

Figure 7. Comparisons of fatigue life for asphalt mix samples without and with rubber particles in PlusRide system.



the presence of the rubber has been reported to prevent the possibility of the bleeding of excess asphalt from the mix since the rubber and asphalt combine to form a more elastic binder.

Costs

Factors that increase the cost of a rubber-asphalt paving mixture over that of a normal mix include the purchase, shipping, and handling of the 60 lb of rubber added to each ton of mix; the plant modifications needed for the rubber addition; and possibly some additional rolling costs. At the current time, the closest rubber production to Alaska is in the Seattle area, and the shipping costs are a major factor in the delivered Fairbanks rubber price of approximately 30 cents/lb. The addition of 3 percent rubber in the Fairbanks area including royality fees paid to the patent holder, All Seasons Surfacings Corporation, will increase the in-place pavement cost by roughly 50 percent, for a total cost increase of $15 000 to $30 000/mile depending on width and thickness.

FIELD TRIALS, FAIRBANKS AREA, 1979

Site Selection

Two sites were selected in the Fairbanks area for the first U.S. trial installations of PlusRide rubber-modified pavement mixtures. The first site, on a frontage road curve, is referred to as the Carnation site after the adjacent Carnation Dairy warehouse. The second site covers the northern half of a roadway insulation test section on the Fairhill Subdivision access road. The Carnation site was selected because of the frequent occurrence of skidding accidents due to the very sharp curvature of the roadway. The existing pavement was constructed in 1967 and was in good condition. Fairhill was selected because the presence of the insulation layer resulted in significant differential surface icing during the 1978-1979 winter, where the roadway was ice-covered above the insulation but not over adjacent noninsulated areas. In this area the original pavement was placed in 1978 and was 24 ft wide.

Pavement Construction

The first Fairbanks-area rubber-asphalt paving mix was prepared on September 4, 1979, by Associated Asphalt Company from Chena River gravels. The rubber was supplied by the All Seasons Surfacings Corporation. Because the asphalt plant to be used was the continuous-mix single-entry drum-dryer type, it was necessary to use the existing stockpile aggregate gradations. As a consequence, the final gradation was slightly lower (4-5 percent) than desirable (6-11 percent) in the dust or fines size range. The rubber was fed from one of the plant's four aggregate-feed bins (Figure 8) after the belt speed had been calibrated to provide a 3 percent rubber content. No problems were encountered in the mixing operation, which appeared to thoroughly distribute the rubber particles through the mix.

At the Carnation site, the mix was placed at an initial temperature of 240°F with a tracked paver in a thickness averaging nearly 2 in. Compaction commenced immediately behind the paver except for an inital delay caused by concern over roller pickup of the mix. Compaction continued until the pavement had cooled below 120°F; minor rebound was still apparent at that temperature. At this site, the final void content ranged from 2.3 to 7 percent and averaged 4.6 percent, slightly higher than the desired average of 3.5 percent.

At the Fairhill site, the mix was truck end-dumped after the application of an RC-800 asphalt tack coat. Placement was performed with a road grader rather than a paver to evaluate the ease of placing this mix with minimal equipment. Unfortunately, the mix proved too sticky for good laydown by this method. The resultant manipulations and delays in final leveling of the mix caused the mix to cool too much for good compaction. Field voids at this site therefore averaged 9 percent, much too high for good durability.

FIELD TRIALS, ANCHORAGE AREA, 1980

Three trial sections of rubber-asphalt pavement were included in the contract for the 1980 Old Seward Highway repaving project. To investigate the effects of a range of rubber contents on performance, provisions were made to place 1.25-in-thick pavement overlays that have rubber contents of 3, 3.5, and 4 percent. Traffic volumes on this road are much higher than those on the Fairbanks sections; the average is 9500 vehicles per day. Preliminary mix designs were prepared for each rubber content and indicated that the original project gradation needed modification to reduce total voids to acceptable levels and still retain some stability. Based on this testing, an increase in the dust content of the mixes to 8 percent was recommended, which reduced the recommended asphalt content to 6.6 percent for all rubber contents.

The rubber-asphalt paving mixes were prepared on June 14, 1980, in a Standard Steel batch plant; the rubber was added by manually breaking the 52-lb bags into a hopper at ground level and feeding the rubber into the mixing chamber by conveyor (Figure 9).

All three different rubber-content mixes were placed with a tracked Barber-Green paving machine and compacted with a minimum of two passes of a vibratory roller followed by two passes of a 12-ton steel-wheel roller. Temperatures of the 3 and 3.5 percent mixes varied from 240 to 280°F at the time of laydown. However, due to equipment and traffic problems, placement of the 4 percent rubber mix was delayed for several hours, and the mix had cooled excessively prior to placement.

Pavement cores taken shortly after placement showed the 4 percent rubber section to have field voids of around 12 percent compared with a desirable average of 3.5 percent, and ravelling and potholing began to occur several days after placement. On the 3 percent and 3.5 percent rubber mixes, field voids averaged 7.5 percent, still much too high for good long-term durability. Analysis of the construction operations indicated the high voids to be the result of aggregates that were out of specification on some sieves and lower than desirable in fines, in com-

bination with a specified asphalt content that was too low and the use of nonvibrated paver screed extensions. This experience is related to make potential users aware that close conformance to specifications and adequate compaction are critical to good performance. Specifications used for the various PlusRide paving mixes placed in 1979 through 1981 are summarized in Table 3.

FIELD TRIALS, 1981

Fairbanks: Peger Road

A total of 280 tons of rubber-modified paving mix was placed in late July at the intersection of Peger and VanHorn Roads. This intersection was chosen because it required a 90° turn on a major truck route.

The mix was produced with a Barber-Green Batch-omatic plant in 3000-lb batches. Mixing started at 8 percent asphalt mixed at 310°F. After it had been noted that no laydown problems were found, the asphalt content was increased to 8.2 percent at 330°F and finally to 8.5 percent at 345°F. At the final asphalt content, some asphalt bleeding was noted in the trucks and the pavement was moderately tender but still placed satisfactorily.

Rolling commenced at a temperature of about 295°F with 10-15 passes of a 10-ton steel-wheel roller and continued until the temperature was below 140°F. Due to tenderness, traffic was kept off until evening cooling had lowered the pavement temperature to 60°F. No subsequent problems were noted, although air temperatures did not exceed 75°F after the date of placement. Subsequent pavement coring indicated voids that ranged from 1.3 to 7.1 percent and averaged 4.2 percent.

Anchorage: Upper Huffman Road

The 1981 Anchorage site, Upper Huffman Road, was chosen because the very steep grades on this road, as high as 14 percent, created a severe traffickability problem during icy winter conditions. A total of 1.01 miles of road was first reconstructed, then paved with a 1.5-in asphalt-concrete binder course, and finally capped with a rubber-modified asphalt pavement 0.75 in thick. The rubber mix was produced with approximately 9.5 percent asphalt in a commercial batch plant at 360°F. Due to the thinness of the lift, cooling was accelerated and field voids were indicated to be approximately 10 percent. However, due to the thin lift and the resultant flexibility of the cores, the laboratory void determinations may not be extremely accurate. The pavement durability to date has been excellent.

Figure 8. Rubber feeding from aggregate bin for dryer-drum mix plant.

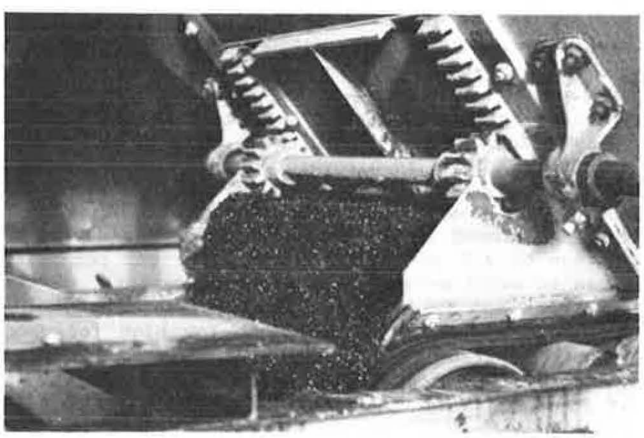


Figure 9. Conveyor loading rubber into pug mill for batch-mix plant.

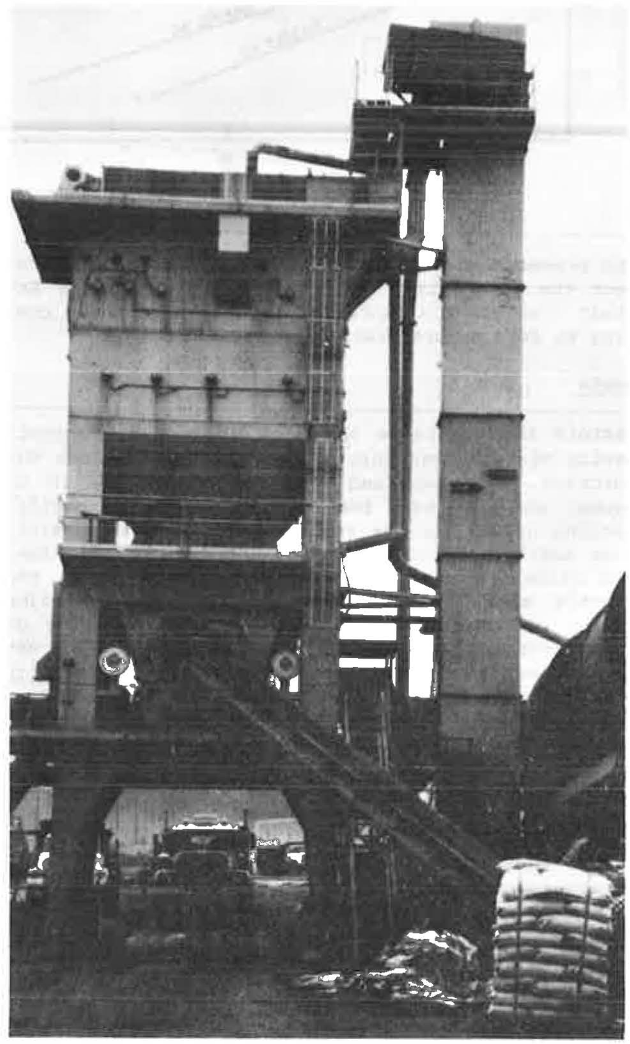


Table 3. Aggregate and mix specifications used for field control of Alaska's rubber-modified asphalt pavements.

Characteristic	Project: Carnation, 1979	Old Seward Highway, 1980	Peger Road, 1981	Upper Huffman Road, 1981
Sieve size (% passing)				
3/4 in	100	100	100	-
1/2 in	-	78-94	-	-
3/8 in	60-77	43-57	53-67	100
No. 4	45-59	29-43	28-42	47-60
No. 10	29-41	22-34	20-32	30-42
No. 40	12-20	15-23	14-22	15-24
No. 200	4-10	5-11	5-11	5-11
Asphalt (% dry aggregate)	7-8	6.1-7.1	8.0-9.0	9.0-10.0
Rubber (%)	3-3.5	3.0-3.5, 4.0	3.0	3.0
Asphalt type	AC-5	AC-5	AC-2.5	AC-5
Avg thickness (in)	2.25	1.5	1.7	0.75
Base	2-in AC	3-in AC	Gravel	1.5-in AC
Length of paving (ft)	212	6792	649	5330

PERFORMANCE OBSERVATIONS

Fairbanks (1979-1980)

Visual surface ice observations were made during the winter of 1979-1980 in an attempt to determine the percentage of time in which the rubber would be of benefit to motorists. A British portable friction tester was used for occasional verifications of observed friction levels under test method ASTM-E303. It became apparent from the field testing that the rubber sections did not have to be totally snow-free or ice-free to show increased friction levels. Results of four icy-road field tests indicated an average increase in the British pendulum number from 42 for the normal pavement to 70 for the pavement with rubber particles.

Public reaction to the rubber sections was favorable. In summary, the 1979-1980 winter performance at the Carnation site was as follows:

1. No skidding incidents where vehicles left the roadway were noticed on this corner after the end of the first snowfall. Skidding off the roadway had commonly been noted at this point in prior years.
2. Improved traction was often noticeable over the rubber area during the early portion of the winter.
3. During much of the winter, thick ice deposits resulting from November rains totally covered the roadway and no benefit of the rubber could again be noted until mid-February. This weather condition was abnormal, and the ice was controlled by frequent sanding.
4. Comments of area drivers indicated that the improved traction was detected by those not aware of the rubber-asphalt test.

Anchorage (1980-1981)

The durability of the high-void rubber-asphalt pavement placed on the Old Seward Highway in June 1980 was very low, particularly for those sections that had rubber contents above 3 percent. Ravelling commenced soon after placement, and it was necessary to patch and eventually repave over the 4 percent rubber area. The center two-thirds of the roadway width over the 3.5 percent rubber area also required repaving during September 1980. Observations for surface ice differences were made occasionally during the 1980-1981 winter on the 3 percent and outer-wheelpath areas of the 3.5 percent rubber areas. However, this winter was exceptionally warm and surface ice was rarely noted on any area pavements.

Fairbanks (1980-1982)

A mu-meter trailer for measuring surface friction was obtained and used for early winter testing to determine the differences in friction between pavements with and without rubber particles at the Carnation and Fairhill sites. However, it rapidly became apparent that this device was unsuitable for measuring friction on icy roads, sanded roads, or PlusRide sections. Test runs on sanded roads demonstrated that the mu-meter, apparently because of its design, could not distinguish friction differences even between glare ice and sanded ice. To provide better data, a Tapley decelerometer was installed in a sedan and used for subsequent measurements of friction levels for PlusRide pavements. This device has the advantage of directly measuring the maximum vehicle braking *g* forces and gives estimated stopping distances from a speed of 25 mph. It has proved to be much superior to the mu-meter and British pendulum tester for measuring the merits of different roadway treatments under icy conditions. The same vehicle was used for all 1981 and 1982 tests.

Testing procedures for stopping-distance comparisons between PlusRide rubber-asphalt and normal asphalt-concrete pavements involved making a series of stops on each surface type. On an icy road surface not in a normal stopping zone, repeated test stops were found to polish the surface and increase subsequent stopping distances, as shown in Figure 10. On the date of this test series, a thin ice cover was present on all sections, but the protruding rubber particles of the PlusRide pavement still resulted in a 50 percent reduction in stopping distances compared with that of adjacent normal pavements.

Results of all stopping-distance tests made on the Fairbanks areas PlusRide sections during the 1980-1981 and 1981-1982 winters are shown in Table 4. Tests results represent the average of two to six stops on each pavement type. For this test series, performed under icy-road conditions with some roadway sand occasionally present, an average reduction of 25 percent in stopping distance was achieved from the use of rubber in the paving mix. No salting for ice control had been done on these pavements. By comparison, tests of bare pavements at these air temperatures indicated minimum stopping distances of 25-30 ft. The use of coarse sands for ice control in similar areas would normally result in reduced stopping distances for only a short period of time, since the sand blows off under traffic action. Results of Tapley-meter stopping tests for sands (1 lb sand/ft^2) on road ice adjacent to the Carnation test site (Figure 11) show that stopping distances at a temperature of -6°F were not significantly reduced from a normal icy-road value of 140 ft by sanding, except for the first two to four stops.

From these comparative tests, it can be seen that stopping-distance reductions achieved with the PlusRide pavements were lasting and quite significant in magnitude, whereas roadway sanding was of only temporary and minor benefit. A few tests of sand applications over PlusRide pavements indicated that significantly greater reductions in stopping distances were obtained from the use of sand than was obtained on normal pavements. The use of rubber in the pavements tested did not provide the same degree of reduction in stopping distances that would have been achieved by salting but did significantly increase the safety aspect at the locations where it was applied. The benefit of the rubber particle (Figure 12) was most notable in higher-speed and higher-traffic areas, where traffic action serves to whisk away the snow and ice particles from the pavement. Applications that meet this criterion and occasionally present icy-surface hazards include bridge decks and insulated roadway sections.

SUMMARY

Between 1979 and 1981, seven experimental rubber-modified pavement sections, which totaled 2.5 miles in length, were constructed by the Alaska Department of Transportation. In these projects 3 to 4 percent of coarse rubber particles were incorporated into hot mixed asphalt pavements by using a system developed in Sweden under the trade name Rubit and now patented in the United States under the name PlusRide. The paving mixes have been successfully prepared in both batch and drum-dryer plants and placed with conventional pavers and rollers. Mix design experience by the Marshall method has demonstrated that the rubber greatly changes the

Figure 10. Tapley-meter test comparisons of stopping distances for rubber-asphalt versus regular asphalt pavement by repeated stops in same wheelpath.

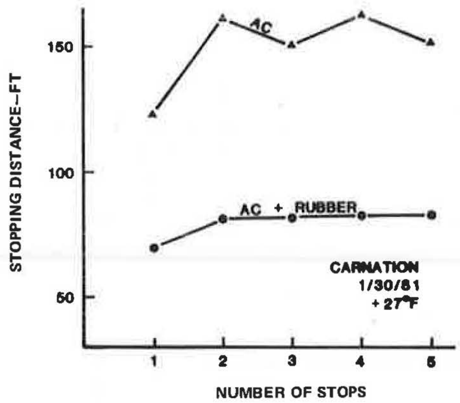


Figure 11. Effects of different sands on stopping distance for repeated stops on smooth road ice.

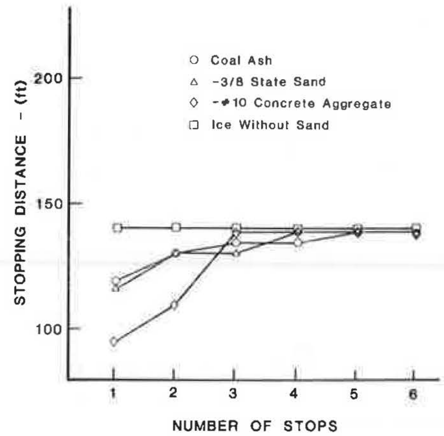


Table 4. Comparative tests of PlusRide and normal AC pavements under icy road conditions at 25 mph.

Date	Pavement Temperature (°F)	Site	Stopping Distance (ft) PlusRide	Stopping Distance (ft) Normal	Percent Reduction with Rubber
01/22/81	-13	Carnation	91	114	20
01/22/81	-13	Fairhill	64	129	50
01/30/81	+27	Fairhill	75	113	34
02/02/81	+27	Carnation	98	101	3
02/05/81	+27	Carnation	53	91	42
02/06/81	+21	Carnation	52	64	19
12/10/81	+13	Peger Road	61	66	7
12/11/81	+6	Peger Road	43	49	12
12/16/81	+6	Peger Road	58	90	36
12/18/81	+18	Peger Road	63	77	18
01/11/82	-9	Peger Road	82	97	15
01/14/82	-11	Peger Road	82	100	18
01/29/82	0	Peger Road	55	109	50
02/02/82	10	Peger Road	80	93	14
02/03/82	17	Peger Road	48	55	13
02/04/82	25	Peger Road	65	80	19
02/09/82	21	Peger Road	70	87	20
02/10/82	14	Peger Road	94	123	24
02/11/82	6	Peger Road	62	124	50
Avg value			68	93	25

mix properties, and from 1 to 2 percent more asphalt is normally required for the attainment of a 3 percent or lower void content, the primary factor used in selection of a suitable mix design. The attainment of a field void level of less than 8 percent, through high asphalt content and compactive effort, has been shown by field experience to be critical to pavement resistance to ravelling. Field voids of less than 5 percent are highly desirable. In spite of the high asphalt contents and soft asphalt grades used in these mixes, no asphalt bleeding has occurred.

Benefits of rubber-modified paving mixes include the ability to shed an ice cover more quickly than conventional pavements, the development of a more flexible and fatigue-resistant pavement, a significant reduction in tire noise, and the beneficial use of what is normally a troublesome waste product, used tires. Under Alaskan conditions of icy non-salted roadways, stopping distances were consistently reduced by the use of rubber-modified asphalt pavements; stopping distances averaged 25 percent less than on normal pavements. Further field and laboratory studies are needed to optimize these benefits and determine the most satisfactory material specifications.

Figure 12. Demonstration of ice-free benefits of rubber-modified asphalt pavement (foreground) versus ice-covered normal pavement (background), Feb. 1980.

ACKNOWLEDGMENT

This research work was accomplished in cooperation with the Federal Highway Administration under the Highway Planning and Research funding program. Appreciation is extended to Nyla Ford, Emory Richardson, and Gary Hicks for information used herein and to Construction and Materials Section personnel of the Alaska Department of Transportation and Public Facilities for design and construction analyses and reporting. The field studies of friction benefits by R. Gaffi were particularly appreciated.

The contents of this paper reflect my views and I am responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Alaska Department of Transportation and Public Facilities or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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Publication of this paper sponsored by Committee on Winter Maintenance.

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Benefits and Costs of Snow Fences on Wyoming Interstate 80

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Snow-fence protection along a 100-km section of Wyoming Interstate 80 has gradually been increased from none to 50 percent since 1970. This presents a unique opportunity to identify effects of the snow fences on snow-removal expenditures, accident frequency, and road closure. This information is needed for economic analyses to determine the feasibility of future snow-control projects. The study indicated that snow-removal costs were reduced by more than one-third as a result of the effective elimination of snowdrifts. Accidents during blowing snow conditions decreased in proportion to the length of highway protected, with a 70 percent reduction at the current level of fencing. There is some indication of a comparable reduction in wind-related accidents. These effects reflect the improved visibility and road-surface conditions observed in the areas protected by snow fences. The fences have had no significant effect on the length of time the highway is closed to traffic, and it is hypothesized that protection might have to approach 100 percent before such an effect could be expected. Fence construction costs can be amortized within 10 years through reduced winter maintenance costs and property damage. Effectiveness of the snow fences is attributed primarily to adequate snow-storage capacity and the use of tall (3.78-m) fences.

On October 3, 1970, a 124-km section of Interstate 80 (I-80) between Laramie and Walcott Junction, Wyoming, was opened to traffic. This new road was in a different location from US-30, which it replaced; by following the old Overland Trail along the foot of the Medicine Bow Mountains, the new route was about 27 km shorter. Because the new highway was in a sparsely populated region up to 30 km from US-30, there was little beforehand knowledge of weather conditions, and highway engineers thought it necessary to gain a winter's experience before building snow fences.

The first winter, large drifts formed on the highway and snow-removal expenditures were excessive in comparison with those on US-30. Frequent ground blizzards caused poor visibility that required the highway to be closed to traffic for a total of 8.4 days. Several factors contributed to more severe snow problems on the new route than had been experienced on US-30. About two-thirds of the old route was immediately downwind of the Union Pacific Railroad, which was well protected with snow fences that also provided protection for US-30, although this was not generally appreciated at the time. The new route is also much closer to the Medicine Bow Mountains, which resulted in more snowfall and stronger winds.

As a result of the first winter's experience, highway engineers gave high priority to construction of snow fences to reduce drifts forming in the road cuts. The first snow-fence construction began in the summer of 1971 and continued into the summer of 1972. By the end of the second winter, it was apparent that fences would alleviate drift formation on the road, but, in addition, dramatic improvements in visibility and road-surface conditions were also evident (1). As a result, additional snow fences have been constructed over subsequent years; the last ones were completed in the summer of 1979. The gradual addition of snow fences along this highway provides a unique opportunity to evaluate their effectiveness in relation to accidents, snow-removal expenditures, and days of road closure. Although there are many published references to the effectiveness of snow fences in qualitative terms, we are not aware of any quantitative evaluation comparable to that provided by this 11-year study.

PHYSICAL AND CLIMATIC CHARACTERISTICS

The section of this highway with the greatest winter weather problems is that between Miles 235 and 295, where the road is closest to the mountains, and this 96.6-km segment comprises the study section. General road orientation is southeast-northwest, and mean elevation over the study section is about 2250 m (Figure 1).

Typically, the first snow falls after mid-September and the last in mid-May. During the study, only 0.8 percent of the ground blizzard accidents were in September and May combined, which led us to choose October 1 to April 30 as the period for the accident analyses. More than 95 percent of the precipitation over this period is snow.

Mean monthly precipitation, wind speed, and air temperature for the study period (1970-1981) are shown in Table 1. Mean water-equivalent precipitation from October 1 to April 30 is 31.1 cm. Snowfall in October and April usually melts within a few days. Most drifting is between November 1 and March 31; precipitation averages 19.8 cm for this period.

Westerly winds are dominant and strongest. Maximum wind gusts up to 45 m/s were recorded in three years of the study. Although major snowstorms are often associated with easterly winds, these are of relatively short duration and are not so strong as the prevailing westerlies. More than 95 percent of the annual snow transport is from the west, and all the snow fences are on the west side of the highway. Because of the strong, persistent winds and long periods of below-freezing temperatures, most of the snowfall is relocated by the wind.

The highway passes through uncultivated rangeland vegetated with low-growing grass and sagebrush 10-45 cm in height; there are only a few isolated groves of trees and taller shrubs. The upwind "fetch"